Forward Drift Chamber for the GlueX experiment at the 12 GeV CEBAF machine

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Abstract. The GlueX experiment will search for exotic mesons produced by 9 GeV linearly polarized photons from the upgraded CEBAF machine. It is critical to detect and measure the four-momenta of all the charged particles and photons resulting from the decays of the mesons. The solenoid-based detector system includes tracking detectors and calorimeters. The Forward Drift Chamber, FDC, consists of 24 circular planar drift chambers of 1m diameter. Additional cathode readout is required to achieve efficient pattern recognition. The detection of low energy photons by the electromagnetic calorimeters imposes constraints on the amount of material used in the FDC. The specific features of the detector and the readout electronics will be described. Results from the tests of the full scale prototype will be presented, as well.

Keywords: hybrid mesons, drift chambers

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INTRODUCTION

The quark model of the mesons as bound states of a quark and an antiquark, is based on the success in explaining the meson spectroscopy only using the quantum numbers of the two quarks. Quantum Chromodynamics (QCD) gives a richer picture of the mesons as strongly interacting quarks and gluons. The inclusion of gluonic degrees of freedom results in predictions for mesons in which the gluons are excited and contribute to the quantum numbers of these so called hybrid mesons. Some of the hybrid mesons have exotic quantum numbers not allowed by the quark-antiquark model. The GlueX experiment [1] will search for such hybrid mesons with masses up to 2.8 GeV. Despite of the extensive experimental search, the results on this are controversial; still there is evidence [2] for a few

isovector exotic states. The existence of hybrid mesons is supported by Lattice QCD calculations [3] that made significant progress during the last years.

The identification of the hybrid mesons with exotic quantum numbers requires measurements of the four-momenta of all the charged particles and photons from the decay of the mesons. This necessitates a hermetic detector with a flat acceptance with respect to the meson decay products. The GlueX detector presently under construction will be installed in the newly built Hall D of the upgraded CEBAF machine at Jefferson Lab. The experiment will use 9 GeV linearly polarized photons produced from the 12 GeV electron beam. The polarization as an additional degree of freedom, is critical for identifying the quantum numbers of the produced mesons.

The GlueX detector (Fig.1) consists of a tracking system that includes the Central Drift Chamber (CDC) and Forward Drift Chamber (FDC), and two electromagnetic calorimeters at the outer side and in the forward direction: Barrel Calorimeter (BCAL) and Forward Calorimeter (FCAL). All the detectors, except FCAL, are placed inside the bore of a solenoid with a longitudinal magnetic field of 2T. The FDC tracks the charged particle in the forward direction. The CDC employs 1.6cm diameter straw tubes used for tracking at large angles and for low energy charged particle identification. The BCAL is a scintillation-fiber/lead calorimeter, the FCAL is a lead-glass calorimeter, both with high energy ($\sim 6\%/\sqrt{E}$) and position ($\sim 6\text{mm}/\sqrt{E}$) resolution, aiming to register the photons in the full 4π acceptance. The Time of Flight scintillator wall will be used for particle identification and timing.

FORWARD DRIFT CHAMBER DESIGN

The FDC will consist of four cylindrical packages, each having 6 drift chamber layers. Each layer (Fig.2) consists of two cathode strip planes on both sides of the wire plane. Each wire plane has alternating sense and field wires 5mm apart. The main design parameters are summarized in Table 1.

The most critical requirement in the FDC design is to minimize the amount of the material not only in the active area of the chamber, but also at the periphery: the frames, supporting systems and cables. At the same time the mechanical structure must be robust enough to exclude deformations and to allow for a good gas tightening. In an early design the chamber frame was made out of solid G10 material. Monte Carlo simulations showed a significant fraction of the photons from meson decays, being converted by the frames and thus not properly reconstructed in the BCAL or FCAL. This required a design change in which the frames are composite: an outer thin G10 skin with an inner part made out of Rohacell material, reducing the total frame thickness by a factor of one half. However, the

1 full scale prototype that was built in this manner showed problems with the gas tightening and robustness of the
2 whole construction. This was mitigated in the final design, where a small fraction of the frame around the gas
3 spacers, is kept solid G10.

4 The high particle densities especially in the forward direction, require good pattern recognition. To achieve this
5 each drift layer has cathode strips from both sides of the wire plane. For a standard drift chamber, using the drift
6 time from one wire plane only, would give two lines parallel to the wire as possible hit positions. The cathode
7 information allows to reconstruct the position of the gas avalanche along the wires. Thus, apart from the left/right
8 ambiguity, each chamber layer provides a spatial point that contributes greatly to identify the charged tracks in a
9 presence of a high magnetic field and to reconstruct the particle's momentum and angle. A resolution of $200\mu\text{m}$ is
10 required for both wire and strip coordinates in order to achieve the physical goals of the experiment.

11 A gas mixture of Ar/CO_2 is our preference, as both gases are non-flammable and neutral. The exact percentage of
12 the components will be determined experimentally based on the stability of operation and the optimum wire and
13 strip resolutions. High argon percentage results in a weaker dependence of the drift velocity on the electric field and
14 better resolution. However, in the presence of a magnetic field one would prefer lower drift velocities and therefore
15 higher CO_2 concentration, to minimize the Lorentz force effects. Detailed simulations and experimental
16 investigations are underway to quantify the magnetic field effects and study the stability of operation in case of low
17 CO_2 admixture.

18 The readout of the full FDC detector will require 2300 wire channels and 10,300 cathode strip channels. It is
19 critical for both, wire and strip resolutions, to have a low noise-to-signal ratio even with a large detector capacitance
20 especially in case of strips with up to 100pF . For that purpose, an eight-channel preamplifier employing a novel
21 ASIC was designed, providing good readout density at reasonable cost. The preamplifier has a peaking time of 11ns .
22 A noise of about $2000\text{e}+20\text{e}/\text{pF}$ has been measured at a gain of $3\text{mV}/\text{fC}$. The ASIC includes also a discriminator that
23 will be used for the wire readout, connected to 48-channel TDC. In case of the strip readout, the differential outputs
24 of the preamplifier are fed into a 72-channel flash ADC with 8ns sampling time.

STUDIES WITH FULL-SCALE PROTOTYPE

Three full-scale drift chamber layers have been built to investigate the chamber performance. The results that will be presented here were done with 40/60% Ar/CO₂ mixture using cosmic tracks, although other studies were done with radioactive sources and other gas mixtures.

The use of flash ADCs provides the opportunity to implement powerful methods to reduce the noise. The noise in adjacent channels with similar strip lengths has similar time structure and magnitude. This allows to subtract the common noise from the signal using the channels not affected by the hit. By reading the flash ADC samples (within a wide enough time window) and applying such a procedure off-line, we were able to achieve a position resolution from the strips as good as 100 μ m (Fig.3). Since the avalanches are created near the sense wires, the strips can be used to reconstruct the wire positions. That allows the estimation of the strip resolution. The strips are oriented at 75° with respect to the wires and a geometrical factor was taken into account to estimate the resolution in reconstructing the position along the wires. The position is reconstructed by calculating the center-of-gravity of the signals above a certain threshold induced on at least five adjacent strips. Thus the resolution is dominated by the signal-to-noise ratio. One can see from Fig.3 that the resolution improves by increasing the signal amplitudes (via high voltage), which means that the signal-to-noise ratio increases at the same time.

To estimate the wire resolution, two chamber layers were placed one on the top of the other, with wires oriented in the same direction. The difference between positions reconstructed from the two chambers was compared with the same difference calculated from the angle of the cosmic track reconstructed with an external tracking system. Because of the small distance between the chambers as compared to the base of the external system, the resolution of the latter doesn't contribute to the presented results. The estimated wire resolution is plotted at Fig.4 as a function of the distance to the wire in one of the chambers, averaged over the same distance in the other chamber. Even the measured resolution reaches the designed value, an additional contribution is expected from the magnetic field effects. Nevertheless, further improvements of the time-to-distance relation and of the gas mixture are studied with Garfield and tested experimentally.

We found that the chamber required higher than expected (from previous studies and also from Garfield simulations) high voltage to achieve maximum efficiency. Further investigations showed that the plateau starts earlier for hits with smaller drift times. This is illustrated at Fig.5 where the mean wire charge is plotted against the drift time. The wire charge was calculated from the maximum wire amplitude, as recorded with the flash ADC,

1 taking into account the preamplifier gain. Thus, it represents the charge integrated over the peaking time of the
2 circuit, rather than the total charge. The drop of the charge with increasing drift time indicates that the electrons
3 recombine while drifting to the anode wire. Garfield simulations including only a 0.1% oxygen contamination
4 (Fig.5) can explain the above behavior. Indeed, the above percentage was confirmed by measuring the oxygen
5 contamination of the gas in the chamber. The contamination is a result of a poor gas tightness due to the fragile
6 g10/Rohacell frames. A mechanical prototype with a solid g10 ring at the position of the gas spacers was
7 constructed. This increased the frame thickness by only a small fraction but at the same time guaranteed the gas
8 tightness of the chamber.

9 SUMMARY AND CONCLUSIONS

10 The GlueX experiment will search for hybrid mesons with exotic quantum numbers not allowed by the
11 quark-antiquark meson model. The Forward Drift Chamber was designed to track charged particles with high
12 resolution needed to identify the decay products of the hybrid mesons. The information from both, the wires and the
13 two cathode strip planes, allows to reconstruct a spatial point within one chamber layer that improves the pattern
14 recognition. The mechanical design reflects the delicate balance between robustness and low detector thickness to
15 allow the photons in the reaction to be registered by the outer e.m. calorimeters. Low noise to signal ratio was
16 achieved by using novel ASIC preamplifier and flash ADC. Studies with a full-scale prototype demonstrated that the
17 designed strip and wire resolutions can be achieved. It was found that the oxygen contamination of the gas was
18 responsible for the poorer signals at larger drift distances. The investigations with the prototype helped to
19 significantly improve the FDC mechanical and electrical design, which production will start at the end of 2010.

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TABLE 1. Main drift chamber parameters.

Parameter	Value
Sense wire diameter	20 μ
Field wire diameter	80 μ
Cell size	10x10 mm ²
Cathode strip pitch	5mm
Active area diameter	1m
Strip to wire angle	75°
Gas mixture	Ar/CO ₂
Gas gain	2 - 8 10 ⁴
Total number of drift layers	24
Total thickness of active area	1.3% R.L.

FIGURE 1. GlueX detector: Solenoid, Central Drift Chamber, Forward Drift Chamber, Barrel Calorimeter, Forward Calorimeter, Time of Flight.

FIGURE 2. One drift chamber layer, from right to left: cathode strip plane, wire plane, spacer ring, second cathode strip plane, ground

FIGURE 3. Preliminary result for the cathode strip resolution in reconstructing the position along the wires, for different sense wire voltages (for Ar/CO₂ 40/60 gas plateau starts at 2000V, field wire at -500V) using cosmics with flash ADC. Not direct measurements (see text).

FIGURE 4. Preliminary result for the wire resolution using cosmic with Ar/CO₂ 40/60 gas mixture at 2225/-500V. Not direct measurements (see text).

FIGURE 5. Preliminary results: Mean charge, as obtained from the flash ADC maximum amplitude, versus drift time, compared to Garfield simulations without and with 0.1% oxygen contamination (2225/-500V sense/field wire voltage, Ar/CO₂ 40/60%).